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Seismic Amplification of Double-Sided Geosynthetic-Reinforced Soil Retaining Walls

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ABSTRACT

This paper examines the seismic amplification behavior of double-sided GRS-RWs using dynamic, 2-D plane strain finite element models. Overall, the seismic amplification of double-sided walls appears to be greater than that of single-sided GRS-RWs. The importance of the fundamental frequency of GRS-RWs to the seismic amplification behavior is observed in cases with low PBA values. However, this importance diminishes with an increase in PBA values as the non-linear behavior of GRS-RWs becomes more important. This non-linearity also changes the variation of seismic amplification with wall height.

Introduction

Geosynthetic reinforced soil earth walls (GRS-RWs) have been used for bridge approach ramps in Indonesia, and they would have to withstand seismic lateral loads. An extensive study is currently underway to understand the behavior of these walls under seismic lateral loads. To verify the behavior of GRS-RWs, a series of laboratory and field pullout experimental studies, as well as pullout numerical studies, has been conducted (e.g., Prakoso et al. 2012, Prakoso and Ilyas 2013, Prakoso et al. 2014).

The seismic amplification of GRS-RWs has been examined by many (e.g., Bathurst and Hatami 1998). Sormin and Prakoso (2013) also reported the results of a series of numerical analyses of single-sided GRS-RWs, adopting the case evaluated by Guler et al. (2012). The paper discussed the effect of peak base acceleration and the backfill material shear modulus on the wall behavior, including the seismic acceleration amplification factor, A_m. Figure 1 summarizes the amplification factor results; overall, the numerical results were within the range of experimental results reported by Kencana (2012). The A_m factor decreased with an increase in the seismic peak base acceleration. The A_m factor also decreased with an increase in the backfill material shear modulus. However, the seismic amplification of double-sided GRS-RWs has not been thoroughly examined.

The objective of this study is to examine whether the seismic amplification of double-sided walls would be different relative to that of single-sided walls, extending the study reported by Sormin and Prakoso (2013). The walls considered are double-sided GRS-RWs with the same height, facing, and reinforcement as those reported previously. The seismic parameters considered are the peak base acceleration and the frequency contents. This paper describes the model used and the cases evaluated, as well the numerical results, particularly in terms of the acceleration amplification factor.

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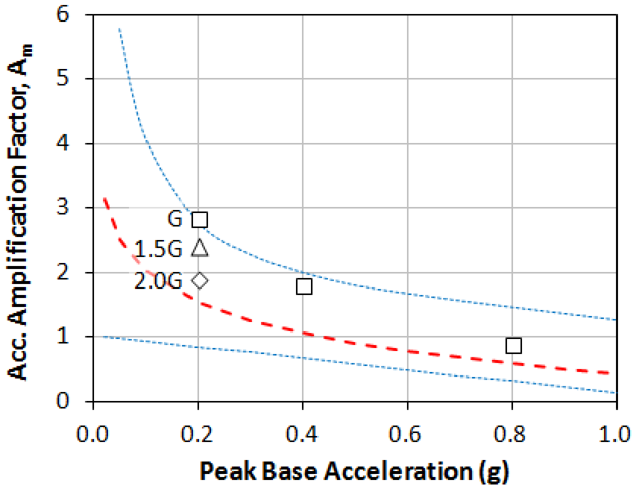


Figure 1. Acceleration amplification factor for one-sided MSEWs (Sormin & Prakoso 2013)

Research Method

The length (H) and width (B) of the GRS-RWs are 6 m and 20 m, respectively. The wall facing is assumed to be modular blocks, with the dimensions of 500 mm × 250 mm. The geosynthetic reinforcement is assumed to be geogrids, with an embedded length (L) of 4.2 m (L/H = 0.7) and a vertical spacing of 1.0 m. There are two soil zones, namely the base soil and the backfill materials; as the focus is on the GRS-RWs, the stiffness and strength of the base soil are much greater than those of the backfill material. This problem is an extension of the problem evaluated by Guler et al. (2012).

The 2-D plane strain finite element method was used to examine the seismic amplification of these walls. The typical finite element model is shown as Figure 2. Six-node triangular finite elements were used to model the soils and the modular blocks, and the number of elements in the typical model was around 600. The Mohr-Coulomb constitutive soil model was used for all the triangular elements, and the material properties are given as Table 1. The geogrids were modeled using elastic tension-only elements (no bending stiffness), and the geogrid axial stiffness (EA) was 10,000 kN/m. No interface elements were used to between the soil elements and geogrid elements. The sides of the base soil were fixed in the horizontal direction, while the bottom of the base soil was fixed in both the horizontal and vertical direction. To avoid spurious reflection during dynamic analyses, absorbent boundaries were specified for the sides and the bottom of the base soil. The damping used was the Rayleigh damping model with factors of $\alpha = 0$ and $\beta = 0.0022$, representing a damping ratio of about 5% (Guler et al. 2012). The numerical study was conducted using geotechnical finite element software Plaxis 2-D (2002).

The input seismic motion was a constant frequency, variable amplitude harmonic acceleration, adopted from Bathurst and Hatami (1998). The harmonic acceleration was 6 seconds long. The range of the peak base acceleration (PBA) varied between 1 m/s^2 and 9 m/s^2, while the range of frequency (f) varied between 1 Hz and 5 Hz. The typical harmonic acceleration time history is given as Figure 3. The acceleration was applied using the prescribed displacement option on top of the base soil. The wall acceleration responses were monitored at different wall heights.

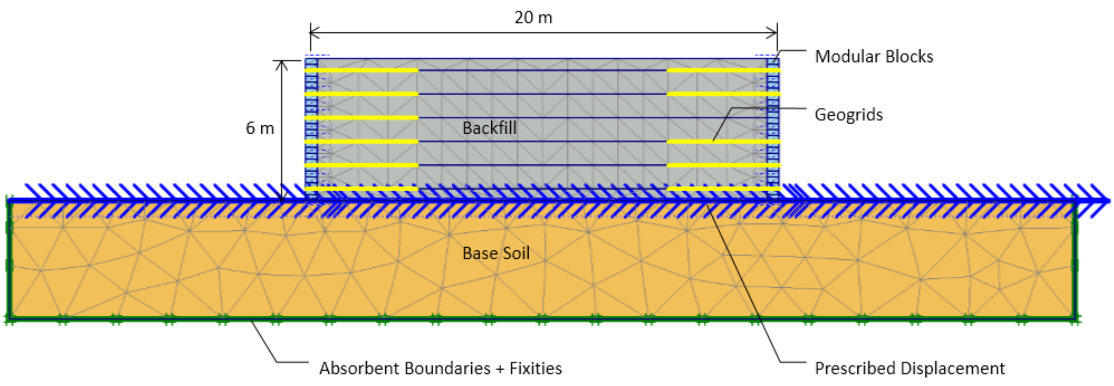


Figure 2. Finite element model

Table 1. Material properties.

Parameter	Base Soil	Backfill	Modular Blocks
Unit weight (γ, kN/m^3)	22	18	20
Elastic modulus (E, MPa)	200	30	30
Poisson's ratio (υ)	0.1	0.3	0.1
Cohesion (c, kPa)	100	5	200
Friction angle (φ, °)	30	35	35

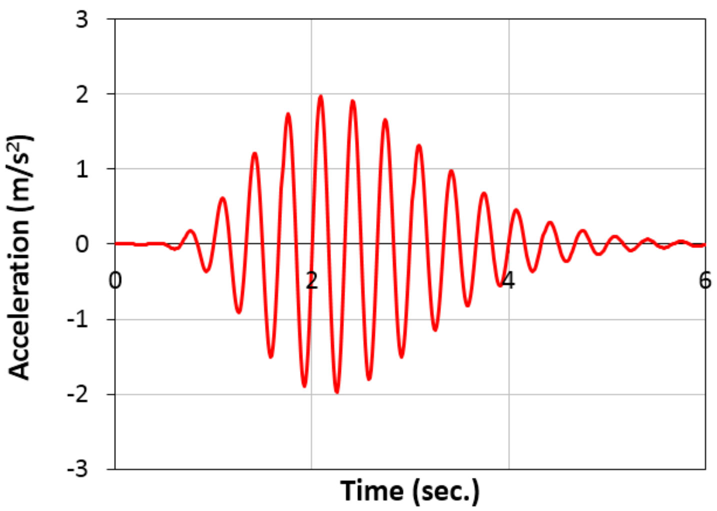


Figure 3. Base acceleration time history (f = 3 Hz, PBA ≈ 2 m/s^2)

Results and Discussion

Model Verification

Numerical studies on geosynthetic reinforced soil earth walls (GRS-RWs) found in the literature were single-sided walls (e.g., Bathurst and Hatami 1998, Guler et al. 2012). Therefore, no direct model verification for double-sided walls could be conducted. As indirect model verification, the model verification was conducted for single-sided walls as reported by Sormin and Prakoso (2013), and the modeling approach was then adopted for the double-sided GRS-RWs.

Typical Results

The typical observed wall horizontal acceleration time history is shown as Figure 4. The time interval was 0.024 seconds. Also shown is the base acceleration time history for a comparison purpose. The horizontal acceleration values of left and right walls at different times are shown as Figure 5. The left wall acceleration at times is different from the right wall acceleration, indicating that the GRS-RW did not vibrate as a rigid body. For any wall, the wall bottom horizontal acceleration could be in a different direction compared to the wall top acceleration, indicating a relatively flexible wall behavior.

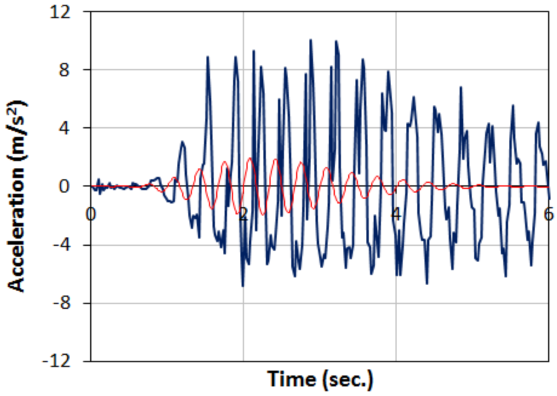
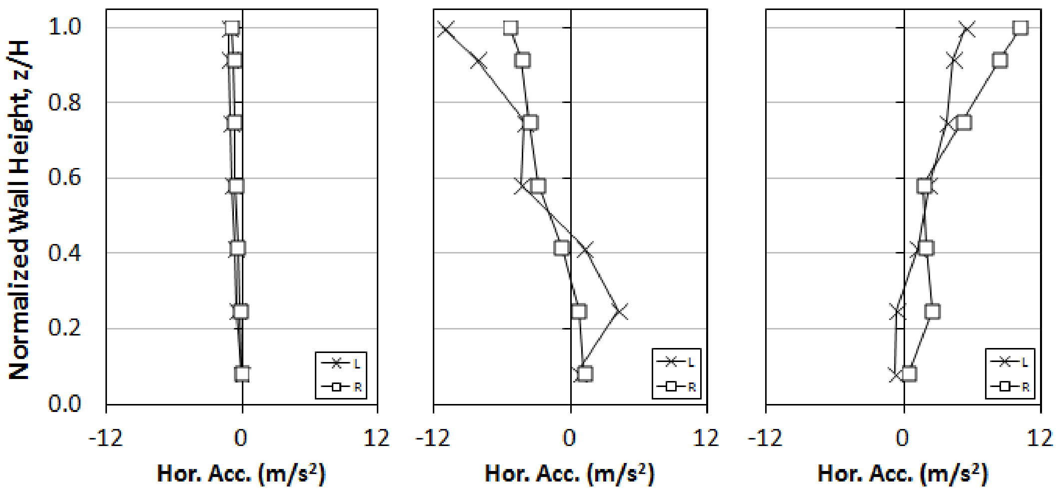


Figure 4. Typical observed wall horizontal acceleration time history (right wall, z/H = 1.0)



a. t = 1.008 sec. b. t = 2.064 sec. c. t = 2.880 sec.

Figure 5. Wall horizontal acceleration at different times (f = 3 Hz, PBA ≈ 2 m/s^2)

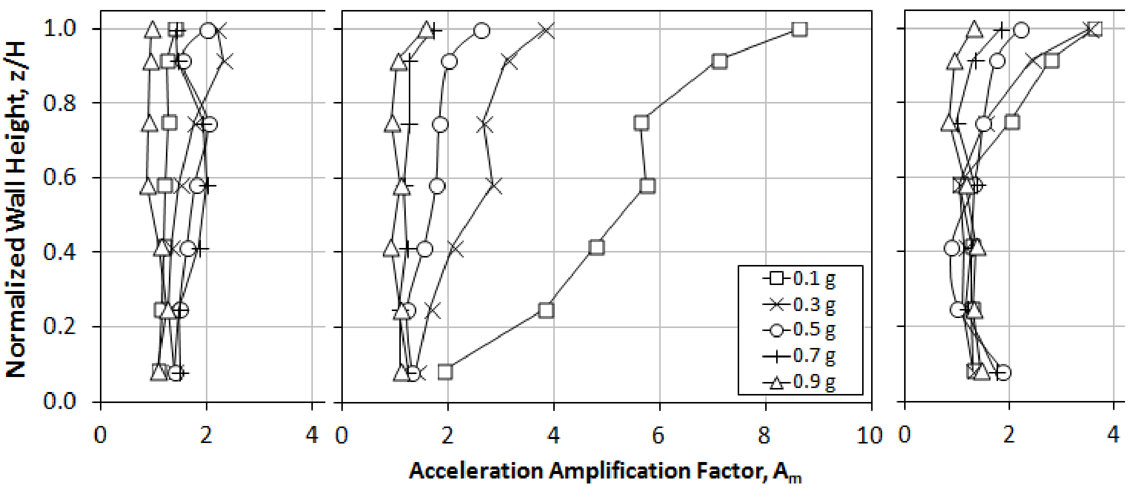
Acceleration Amplification Factor

The seismic acceleration amplification factor A_m is defined as the ratio of the observed peak wall horizontal acceleration to the input horizontal peak base acceleration (PBA). For the case shown in Figure 4, the A_m factor is 5.13 (= 10.105 m/s^2 / 1.97 m/s^2). It is noted that, the A_m factor discussed in this paper is that for the right wall.

The A_m factors for GRS-RWs at different wall heights are shown as Figure 6, and those for different frequencies and different peak base acceleration values are given. As wall acceleration at any given time varies with heights as shown by Figure 5, the enveloping A_m factors also vary with heights, with the general trend of wall top experiencing the highest A_m factor. This trend is consistent with the experimental results reported by Kencana (2012). The interacting effect of wall heights and PBA on the A_m factors is examined further in Figure 7 for the base acceleration frequency f = 3 Hz. In general, the A_m factor decreases with an increase in PBA. The A_m factors for different wall heights vary significantly for low PBA values [PBA = 0.1 g: from 3.8 (z/H = 0.25) to 8.6 (z/H = 1.0)], but they tend to be quite similar for high PBA values [PBA = 0.9 g: from 1.10 (z/H = 0.25) to 1.56 (z/H = 1.0)].

A similar trend of A_m factor – PBA relationship was also observed for single-sided GRS-RWs in the experimental setting (e.g., Kencana 2012) and in the numerical simulations (e.g., Sormin and Prakoso 2013). However, by comparing Figure 7 to Figure 1, it could be observed that the A_m factor for double-side GRS-RWs tends to be greater than that for single-sided walls. Furthermore, it has been shown (e.g., Kencana 2012, Sormin and Prakoso 2013) that the de-amplification of seismic acceleration occurs for single-sided walls with high PBA values. However, a similar de-amplification was not observed for double-sided walls with high PBA values in this study.

Figure 6 also indicates that, for a given peak base acceleration value, the A_m factors also varies with seismic frequencies. The interacting effect of base acceleration frequency and PBA on the A_m factors is examined further in Figure 8. For a low PBA value, the variation of A_m factors is very significant; for PBA = 0.1 g, the wall top A_m factors vary from 1.4 (f = 1 Hz) to 8.6 (f = 3 Hz). However, for a high PBA value, the variation is much less; for PBA = 0.9 g, the wall top A_m factors vary from 0.95 (f = 1 Hz) to 1.56 (f = 3 Hz). This interacting effect is also examined in Figure 9. For f = 1 Hz, the wall top A_m factors vary from 0.95 to 2.2, while for f = 3 Hz and 5 Hz, the A_m factors vary from 1.6 to 8.6 and from 1.3 to 3.6, respectively.



a. f = 1 Hz b. f = 3 Hz c. f = 5 Hz

Figure 6. Acceleration amplification with wall heights

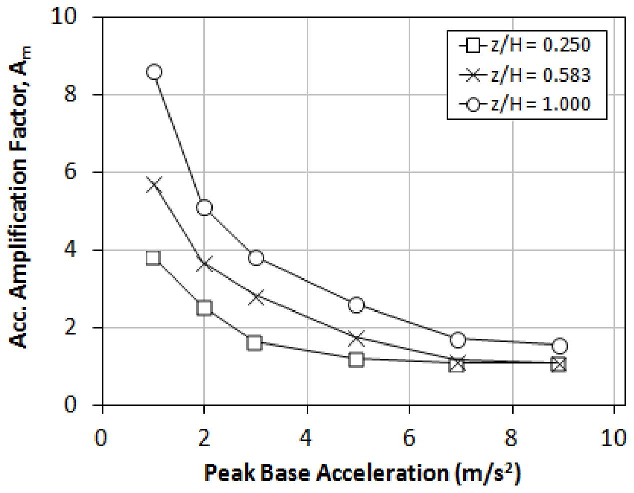


Figure 7. Effect of PBA and wall heights on A_m factor (f = 3 Hz)

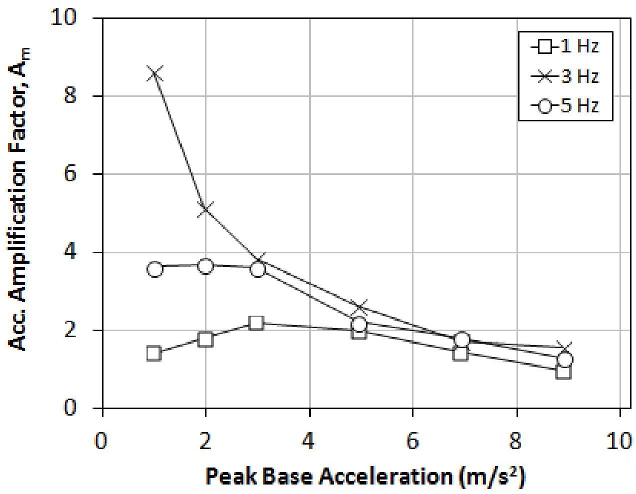


Figure 8. Effect of PBA and frequency content on A_m factor (z/H = 1.0)

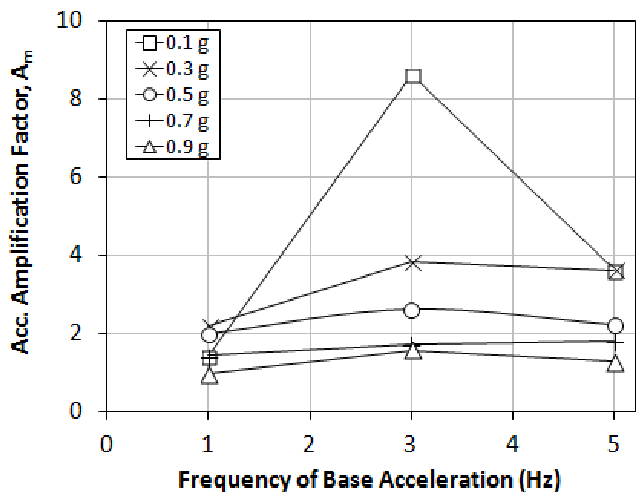


Figure 9. Effect of frequency content and PBA on A_m factor (z/H = 1.0)

The frequency-dependent A_m factor for low PBA indicates the importance of GRS-RW fundamental frequency or natural period on its seismic behavior. Bathurst and Hatami (1998) indicate that Wu's equation could be used to estimate the first mode fundamental frequency of GRS-RWs. It is recognized that the rigid body assumption of Wu's equation is not completely compatible with the observed GRS-RW behavior previously discussed. However, it is used as a first order estimate of the fundamental frequency for the GRS-RWs examined in this study, and the estimated fundamental frequency is 3.7 Hz. The nearest frequency of base acceleration to the fundamental frequency f is 3 Hz. This explains that the larger A_m factors for f = 3 Hz are due to the resonance of the seismic base acceleration.

The A_m factor is relatively frequency-independent for high PBA. This is apparently related to the non-linear behavior of GRS-RWs as suggested by many (e.g., Kencana 2012). The non-linearity causes a relatively high system damping so that the closeness of the fundamental frequency of GRS-RWs to the base acceleration frequency would not affect the A_m factor significantly. This non-linearity appears to change the effect of the wall height factor on the A_m factor as well.

Conclusions

This paper examined the seismic amplification of double-sided geosynthetic reinforced soil earth walls using dynamic, 2-D plane strain finite element models. The wall facing and reinforcement were modular blocks and geogrids, respectively. The seismic parameters considered were the peak value and frequency of the base acceleration. The resulting A_m factor varied from greater than 8 to less than 1. Overall, the seismic amplification of double-sided walls appeared to be greater than that of single-sided GRS-RWs. The importance of the fundamental frequency of GRS-RWs to the seismic amplification was observed in cases with low PBA values. However, this importance diminished with an increase in PBA values as the non-linear behavior of GRS-RWs became more important. This non-linearity also changed the variation of seismic amplification with wall heights; for low PBA the wall height factor was important, but for high PBA, the factor appeared to be less important.

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